Contract Summary	
Title	Progress Report for N00014-19-C-1057
Created By	Gary Raven
Date	12/06/2019
Contract Number	N00014-19-C-1057
Contractor	GenXComm, Inc 10000 Metric Blvd., Suite 200 Austin, Texas 78758-5208
Project Title	Beyond Smart: Optical Neural Networks for Intelligent Electronic Warfare
Contract Performance Period	09/30/2019-03/30/2020 (b)(4) ▓▓▓▓▓▓▓▓▓▓ (b)(4) ▓▓▓▓▓▓
Report Covers	11/01/2019– 11/30/2019 (costs through 11/30/2019)
Distribution	daniel.s.green2@navy.mil kevin.r.leonard@navy.mil adrien.m.fairweather.ctr@navy.mil Brigid.sanders.ctr@navy.mil Director, Naval Research Lab Defense Technical Information Center
Information Security	UNCLASSIFIED
Notice	GenXComm Proprietary

Financial Summary						
Total Contract Amount ($)	393,468.00 (b)(4) ▓▓▓▓▓▓▓▓▓▓					
Total Amount Expended ($)	(b)(4) ▓▓▓					
Total Amount Invoiced ($)	(b)(4) ▓▓▓					
Total Amount Paid ($)	(b)(4) ▓▓▓					
Total Invoiced Less Expended ($)	(b)(4) ▓▓▓					
Total Paid Less Expended ($)	(b)(4) ▓▓▓					
Total Funded Less Expended ($)	(b)(4) ▓▓▓					
Estimate to Complete ($)	(b)(4) ▓▓▓					
Cost of Work Per Month ($)	1	2	3	4	5	6
Direct Labor	(b)(4) ▓▓	(b)(4) ▓▓				
ODC	▓▓	▓▓				
Other	▓▓	▓▓				
Total	▓▓	▓▓				

Abstract

During this second reporting period an analysis of ONN performance including thermal effects was performed. Initial data preparation for training and inference tasks was performed and analysis (through simulation) of inference accuracy was completed. In addition, design of the proposed optical neural network was initiated in preparation for the design review in January.

Project Status

Schedule Status

The project is currently on schedule overall. *Task 1: Kickoff and Performance Analysis* is complete. *Task 2: Modeling and Simulation* is near completion and *Task 3: PAC and ONN Design is partially complete.*

Financial Status

(b)(4)

Technical Risks

Nothing to report.

Management Issues

Nothing to report.

Meeting Minutes

Regular program status meetings held each Monday. Meetings involved updates to percent complete and discussion of tasks to be performed.
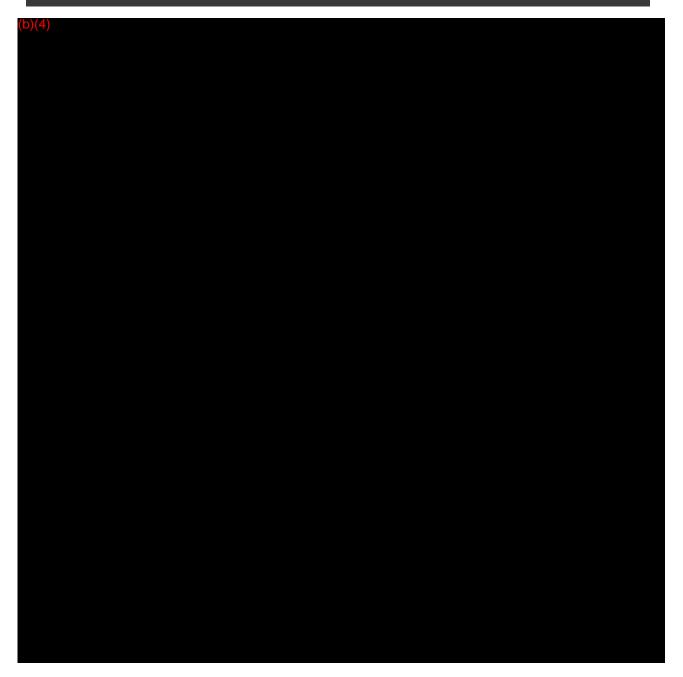
Deliverables

The following CDRLs were delivered during this period (in addition to regular reporting CDRLs).

Requested Government Actions

Nothing to report.

Schedule

#	Milestone	Date	Completed	Description
M1	Program Kickoff	10/18/2019	10/28/2019	Program Kickoff Meeting at ONR facilities to review program plan, schedule and objectives.
M2	Design Review	1/3/2020		Review of detailed module and system designs with ONR
M3	Delivery	3/13/2020		(b)(4)
M4	Final Report	3/30/2020		Delivery of final report describing performance of ONN subsystem, roadmap for capability evolution and planned OY1 activities.

(b)(4)

Technical Progress

During this second reporting period an analysis of ONN performance including thermal effects was performed. Initial data preparation for training and inference tasks was performed and analysis (through simulation) of inference accuracy was completed. In addition, design of the proposed optical neural network was initiated in preparation for the design review in January.

Design and Simulation

Optical neural network performance scaling with loss

An optical neural network (ONN) with L number of layers, N number of neurons in each layer, and considering $U\sum V^{\dagger}$ implementation of the matrix multiplexer in each layer, requires $L \times N^2$ MZI units. (b)(4)

(b)(4)

Considering $U\sum V^{\dagger}$ implementation of the matrix multiplexer in each layer, the floating-point operations per second (FLOPS) of the ONN with the operation speed of B is given by

$$FLOPS = 4 \times L \times N^2 \times B$$

Note that with the $U\sum V^{\dagger}$ decomposition any arbitrary matrix can be implemented. However, for the machine learning (ML) applications, implementing each layer with a single unitary matrix would still provide proper responses. If the matrix multiplexer in each layer of the ONN is implemented by a unitary matrix. The FLOPS is given by

$$FLOPS = 2 \times L \times N^2 \times B$$

Figure 5(a) and 5(b) show the FLOPS of an optical neural network (b)(4) for scaling the width and depth of the ONN with each layer implemented based on $U\sum V^{\dagger}$ decomposition and a single unitary matrix, respectively. The values in Fig. 1 are presented in tera FLOPS which is $10^{12} \times$FLOPS.
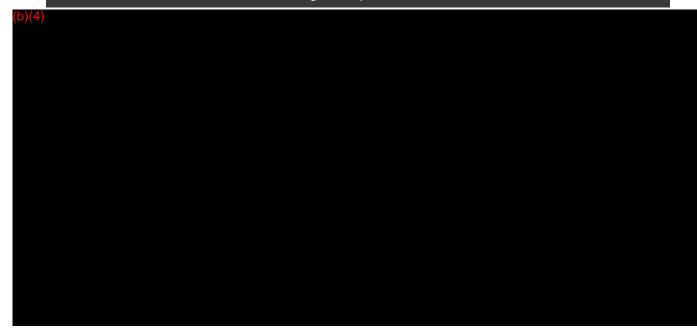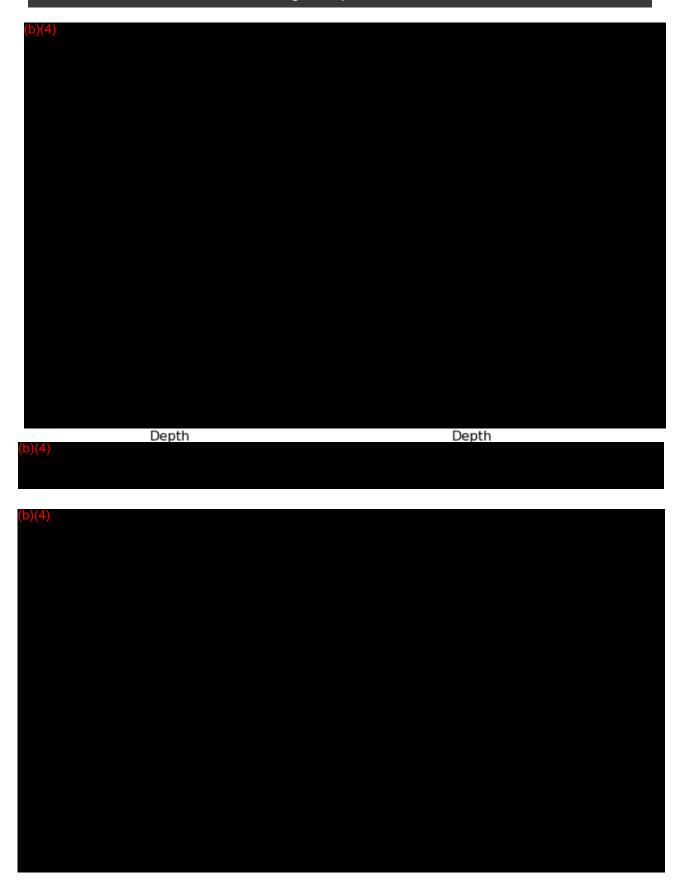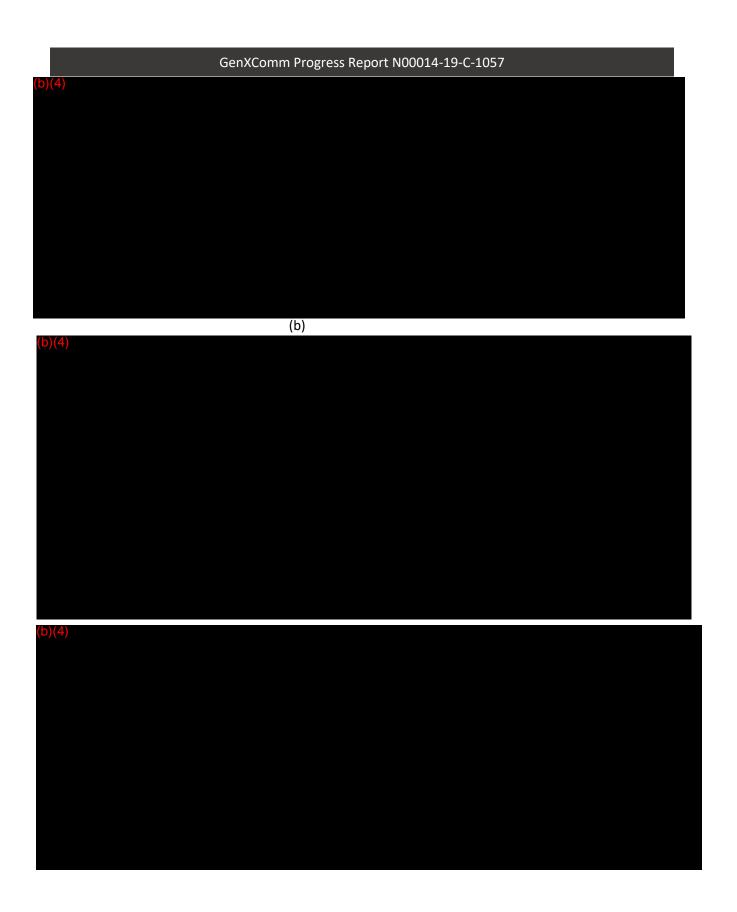
(b)(4)

Table 1 summarizes the assumptions for calculating the required optical laser power and electrical power consumption for various widths and depths of the ONN. Figures 2 demonstrate the required laser power and the power consumption as a function of ONN scaling for when each layer of the ONN implemented based on a single unitary matrix (Fig. 2(a) and 2(c), respectively) and based on the $U\sum V^\dagger$ decomposition (Fig. 6(b) and 6(d), respectively).
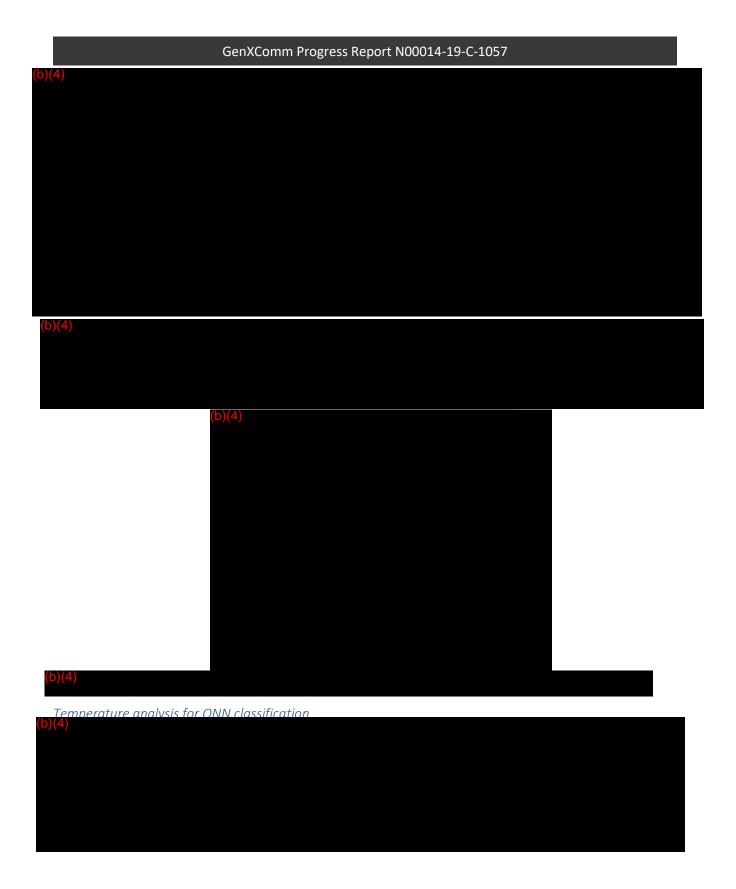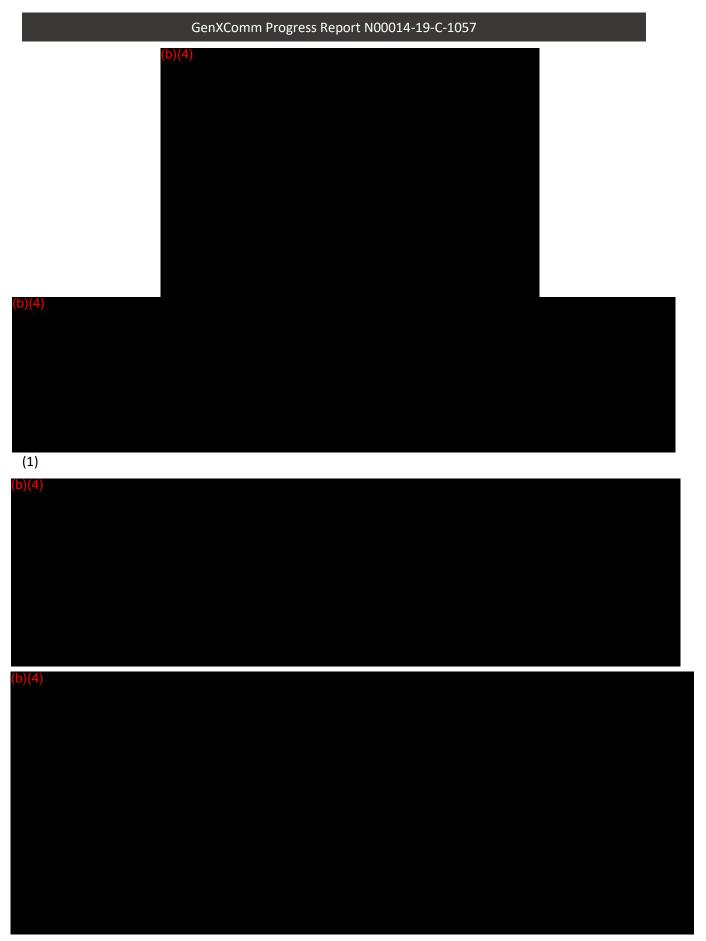
Table 1. summary of the ONN characteristics.

Parameters	Unit	Value
(b)(4)	(b)(4)	(b)(4)

(b)(4)

Depth   Depth

(b)(4)

(b)(4)

(b)(4)

(b)

(b)(4)

(b)(4)

(b)(4)

(b)(4)

(b)(4)

(b)(4)

Temperature analysis for ONN classification

(b)(4)

(b)(4)

(b)(4)

(1)

(b)(4)

(b)(4)

(b)(4)

(b)(4)

(b)(4)
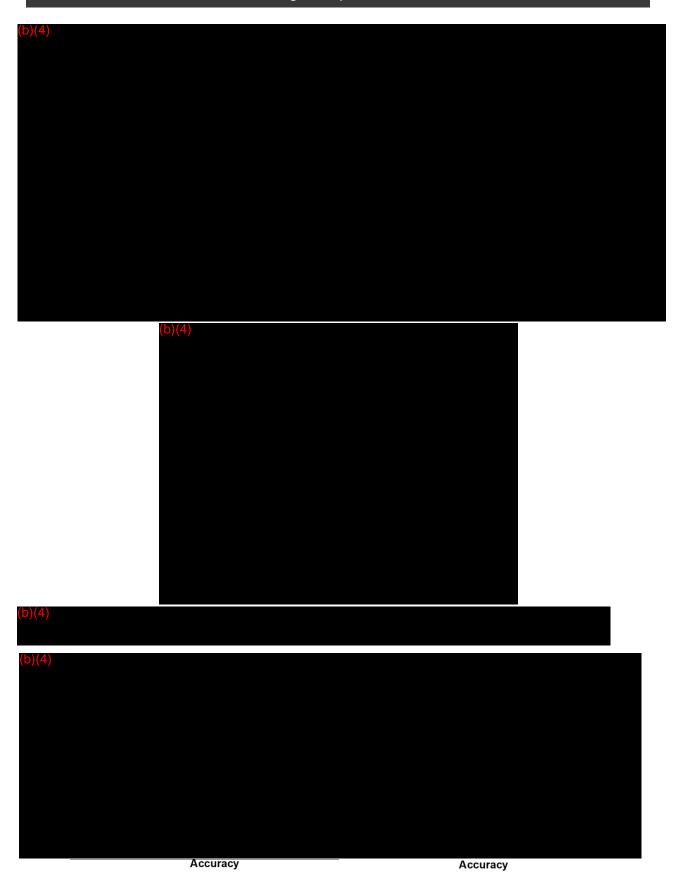
(b)(4)

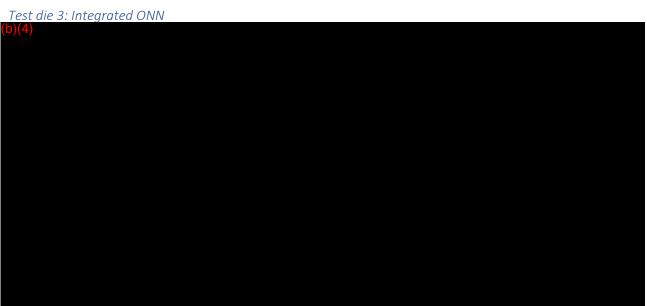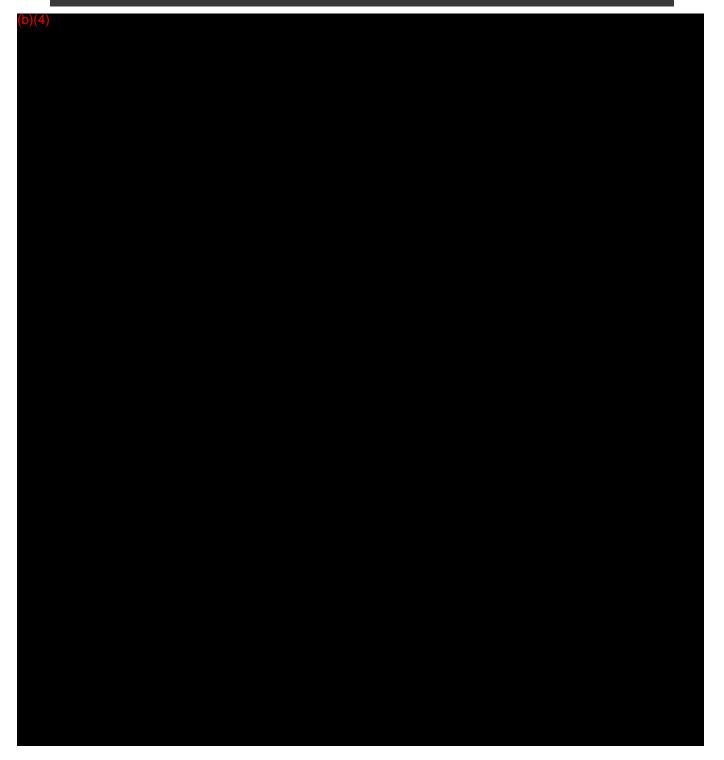Accuracy   Accuracy

(b)(4)

Test chip design and layout

After completing our design and simulation of relevant ONN components, we have designed masks to fabricate and test the designed components to tune the performance for our ONN. The following describe the fabricated masks.

Test die 1: ONN components

(b)(4)

(b)(4)

(b)(4)

Test die 3: Integrated ONN

(b)(4)

(b)(4)

References

[1] Xiao, Shijun, Maroof H. Khan, Hao Shen, and Minghao Qi. "Modeling and measurement of losses in silicon-on-insulator resonators and bends." *Optics Express* 15, no. 17 (2007): 10553-10561.

[2] Chrostowski, Lukas, and Michael Hochberg. *Silicon photonics design: from devices to systems*. Cambridge University Press, 2015.